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TURBIDITIES OF AMERICAN AIR MASSES AND CONCLUSIONS REGARDING THE SEASONAL VARIATION IN ATMOSPHERIC DUST CONTENT

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This paper deals with a statistical study of atmospheric turbidity for Lincoln, Nebr., Madison, Wis., Washington, D. C., and Blue Hill, Milton, Mass. Means for various air masses are presented, together with several situations showing changes in turbidity of the same air mass as it passes each station. Also conclusions are offered regarding an autumn-winter-spring variation in atmospheric dust content.

The Linke turbidity factor T is defined by Linke (**6**) as the ratio of the atmospheric extinction coefficient to the molecular extinction coefficient.[1] Since atmospheric depletion of solar radiation is due not only to molecular scattering but also to dust scattering and absorption by water vapor, the Linke factor is always greater than unity. It is defined mathematically as

$$T=\frac{1}{a_m m}\log_e\frac{I_o}{I}=P(m)\log_{10}\frac{I_o}{I},$$

where I_o is the solar constant corrected to actual solar distance; I is the total intensity of the direct solar radiation; m is the optical air mass computed from the solar altitude; and a_m is the molecular scattering coefficient and is a function of m.

Hence, by observing I and m, T may be easily computed. The function $P(m)$ has been computed by Feussner and Dubois (**2**) and is tabulated on page 23 of the monograph by Haurwitz (**4**).

The normal intensities of solar radiation for Lincoln, Madison, and Washington were taken directly from the observations published in the MONTHLY WEATHER REVIEW and cover the period from January 1931 to May 1933, excluding the months June, July, August, and September because of lack of analyzed maps. The published values are for integral values of m only and are derived by the observer from interpolation and extrapolation of the original intensities. For Blue Hill the original observations (not the values for integral optical air mass published in the MONTHLY WEATHER REVIEW) were used; the period covered is from December 1932, immediately after the solar radiation program at Blue Hill was begun, to May 1933. The synoptic air masses present at the various stations were identified from the synoptic charts analyzed by the Meteorological Division of Massachusetts Institute of Technology.

Since local conditions of smoke, dust, haze, and clouds may influence turbidity, a detailed description of the exposures of the various instruments is necessary. At Washington, Lincoln, and Madison, the Marvin type pyrheliometer is used; a description of the exposures at these stations is quoted in part from Kimball (**5**) p. 26:

> At Washington [38°56′ N., 77°05′ W., 397 feet mean sea level] the measurements are made on the campus of the American University about 5½ miles northwest of the United States Capitol. There are no manufacturing establishments within a radius of about 3 miles, but the suburb about the university is rapidly building up, principally with detached houses. The pyrheliometer is exposed on a shelf outside a window, in the morning on the southeast side of the building and in the afternoon on the southwest side. At times, with southeast or east winds, city smoke is brought over the university.
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> At Madison [43°05′ N., 89°23′ W., 974 feet mean sea level] the pyrheliometer is installed in North Hall, University of Wisconsin, and exposed on a shelf outside a window facing east in the morning and west in the afternoon. North Hall is on a bluff in the upper campus, a short distance from the south shore of Lake Mendota. Most of the manufacturing plants are in the eastern part of the city, but railroad tracks and the heating plant of the university are to the southwest. With a northwest wind the air is free from smoke, but with the wind from other directions considerable smoke is brought over the campus.
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> At Lincoln [40°50′ N., 96°41′ W., 1,225 feet mean sea level] the pyrheliometer is exposed in the experiment-station building, on the farm campus, State university farm. It is 2½ miles northeast of the center of the business section of the city, but there is some smoke from buildings on the farm campus and from railroads and shops not far to the north. Under certain conditions the city smoke cloud covers the farm campus, but with a west to northwest wind the atmosphere is very clear. When observing the pyrheliometer is exposed on a shelf outside a south dormer window.

At Blue Hill [42°13′N, 71°05′ W, 640 feet mean sea level], the pyrheliometer is of the Smithsonian silver-disc type and is exposed on the tower of the observatory, 672 feet above sea level and about 400 feet above the surrounding countryside. The area of maximum smoke production is at Boston, about 6 to 12 miles away, and subtends an angle from about NNE. to NW. Minor smoke sources are located to the northwest in the suburbs of Boston, to the southwest at the small town of Canton, 4 miles distant, and to the southeast in Brockton, a city of about 50,000 population, 10 miles away. Providence and Fall River, large factory cities, are 30 to 40 miles SW. to S. The surrounding countryside is mostly forest and meadow. The Atlantic Ocean subtends an angle from NE. to about SSW. and varies in distance from about 10 miles to the northeast and east to about 60 miles to the south.

In order to obtain turbidity factors which are representative of the prevailing air mass type, observations which are affected by local conditions of clouds, smoke, fog, dust, etc., must be eliminated. For Madison, corrections from January to October, 1931, could be made only by consulting the 7 a.m. and 7 p.m. reports at La Crosse, 100 miles to the northwest. The hourly observations of wind, sky, clouds, visibility and ceiling taken at

[1] T may be also defined approximately as the number of clean, dry atmospheres which would diminish the direct solar intensity by the same amount as does the single, moist, dirty atmosphere.

the newly established airways station from October 1931 to March 1933 were consulted.[2] For Lincoln, the 7 a.m. and 7 p.m. observations at Omaha, 50 miles to the northeast were used until October 1931 after which time observations of wind, cloud, and sometimes visibility were available from Lincoln itself. For Washington, the 8 a.m. and 8 p.m. reports on the weather maps were taken. At Blue Hill, observations of sky, cloud, wind and visibility, which were taken simultaneously with the solar observations, permitted a careful check on the local conditions.

It is desirable at this point to examine briefly whether the Linke factor satisfies two of the fundamental properties that a true turbidity measure should have:

(1) *Uniqueness:* that is, to a given optical state of the atmosphere there must correspond a constant measure of turbidity which shall be independent of the solar altitude and thus measurable at any time during the day. Feussner and Dubois (2) publish the following table, showing the virtual range of the Linke factor with optical air mass for a clean moist atmosphere of varying amounts of precipitable water.

TABLE 1.—*The virtual range of the Linke factor with optical air mass (m) for a clean moist atmosphere for varying amounts of precipitable water (w)*

w \ m	1	2	3	4	6	8	10	15
0.5 cm	1.71	1.64	1.67	1.65	1.64	1.66	1.66	1.72
1 cm	2.22	2.03	1.98	1.95	1.93	1.94	1.95	2.04
3 cm	3.33	2.92	2.81	2.77	2.83			

From this it appears that T (for small values of m) decreases with increasing m and increases with increasing w. The percent change in T is greatest for an increase in m from 1 to 2, and is equal to about 4 percent for $w=0.5$ cm and 12 percent for $w=3.0$ cm. When m increases from 2 to 3, the change is smaller, being less than 2 percent for $w=0.5$ cm and less than 4 percent for $w=3.0$ cm. For further increases in m the differences become even smaller. Now the majority of solar observations published in the MONTHLY WEATHER REVIEW correspond to the optical air masses 2, 3, and 4, and, as shown in table 1, the virtual range for these air masses is small, amounting to less than 4 percent for 3 cm of precipitable water—a high water content of the atmosphere on days suitable for solar observations during the nonsummer months. For Blue Hill, most of the observations are taken within air masses 2 to 4 except for those taken in the spring and early autumn, when the majority of observations are closely grouped around some value of $m<2$, because then the high altitude of the sun causes an air mass of less than 2 to prevail for several hours before and after local noon. Hence, the virtual range of T in a clean, moist atmosphere is within 4 percent for the majority of observations. Concerning the effect of dust on the range of T nothing seems to be known. An example of the scattering of values of T in a synoptic air mass whose optical state is more or less constant, is shown in table 2, observations taken at Blue Hill on February 9, 1933, a day on which a deep current of Polar Continental air was passing over the station and the ground was covered with snow.

The irregular fluctuations in T are probably due to observational errors. The increase of T with m in the afternoon probably follows the wind shift to a more southerly quarter accompanied by an increase in water vapor and perhaps in dust content as shown by the increased cloudiness and decreased visibility.

[2] However, for April and May, 1933, the regular morning and evening observations at Madison were used.

TABLE 2.—*Atmospheric turbidity at Blue Hill, Mass., during Feb. 9, 1933*

m	T	Sky conditions	Wind
3.57	1.85		
3.45	1.78	Few Frcu	
3.34	1.78	Visibility 9	WNW. 17 m.s.
3.03	1.69	Horizons clear	
2.95	1.73		
2.88	1.68		
2.74	1.69		
2.68	1.72	Few Cu and Frcu	WNW. 19
2.62	1.71		
2.51	1.88		
2.48	1.83		
2.44	1.85		
2.08	1.87		
2.06	1.96	Few Cu and Frcu	
2.03	1.83	Visibility 10	WNW. 15.
1.97	1.95		
1.95	1.92		
1.94	1.85		
1.89	1.98		
1.88	2.19	Few Cu and Frcu	
1.87	1.97	Visibility 10	WNW. 15.
1.83	1.77		
1.83	2.09		W. 15.
2.42	2.21		WSW. 10.
2.44	2.13		
2.72	2.12	2/10 Cu and Frcu	WSW. 9.
2.79	2.10	Visibility 8	
2.86	2.10		
Mean	1.90		

(2) *Reduction of T to Standard Level:* For purposes of comparison, it is important that the turbidities observed at stations of different elevation be reduced to a standard level. Feussner and Dubois (2) give a formula for reducing turbidity values to the 760 mm *Hg* surface by assuming that the dust and water content of the air column above the standard level is exactly the same as that above the level of the observing station. In this case, then, the correction is negative; for Lincoln, Nebr., the highest of our stations, the correction is -0.02 for turbidities between 1.42 and 1.62 and -0.14 for turbidities between 3.93 and 4.34. Corrections for elevation were made for Lincoln, Madison, and Blue Hill, but for Washington they were omitted, being practically negligible at such a low elevation.

The designations of the synoptic air masses introduced into this country by the Meteorological Division of the Massachusetts Institute of Technology are followed here. Although Willett (8) has described the characteristic properties of these various air masses in detail, it is desirable to include here a brief description of them. *Polar Continental Air* (*Pc*) acquires its properties over northern Canada and Alaska; besides being dry and cold, it is relatively free from dust. *Modified Polar Continental Air* (*Npc*) is air of polar continental origin which to some extent has lost its original coldness and dryness in the lower layers, and is usually characterized by marked inversions, probably due to subsidence, above which the accumulated pollution and moisture cannot rise. *Modified Polar Pacific Air* (*Npp*) is of polar origin, warmed and moistened in its lower layers by passage over the northern Pacific Ocean, but which has lost most of its moisture and acquired dust, smoke, etc. before reaching the eastern United States. *Tropical Maritime Air* (*Tm*) originates over the Gulf of Mexico or the adjacent portion of the Atlantic Ocean, and is characterized by warmth and high moisture content in the lower layers. *Tropical Continental Air* (*Tc*) is air from the hot, dry, southwestern portion of the United States and Northern Mexico and has low moisture content but a high dust content.

Pyrheliometric observations taken in the neighborhood of a front, where 2 types of air mass may have been present, 1 on the surface, the other aloft, were eliminated. In determining the turbidities characteristic of the different types of air, and the changes in these turbidities as the air mass moves across the country, no attempt was made to note the change in turbidity of an individual air column because of lack of an adequate number of solar stations and the difficulty of determining the true trajectory from only twice daily reports. The air over Lincoln and Madison in general has traveled over cleaner regions than that over Blue Hill or Washington. Hence, when we speak of "the change in turbidity of an air mass moving across the country" we refer to the change in turbidity brought about by differences in the trajectories of the air streams. However, the change in turbidity of a single air column may be approximated in the case of an anticyclone which, after moving eastward, becomes stationary for several days; such a situation, that of October 15–22, 1931, is discussed later.

The mean turbidities for the various stations and synoptic air masses are given in table 3. The observations for Lincoln, Madison, and Washington cover the period from January 1931 to May 1933, omitting the months June, July, August, and September, because of lack of maps analyzed by the Massachusetts Institute of Technology for this period during 1931 and 1932. The subscripts attached to the turbidities refer to the number of days of observation. Days on which observations were widely scattered or less than two in number were eliminated.

TABLE 3.—*Mean turbidities of synoptic air masses*

	Lincoln, Nebr.	Madison, Wis.	Blue Hill, Mass.	Washington, D. C.
Pc	1.87_{23}	2.00_{30}	2.08_{15}	2.54_{26}
Npp	2.34_{95}	2.35_{44}	2.55_{15}	2.62_{43}
Npc	2.46_{28}	2.55_{35}	2.76_{25}	2.80_{34}
Tm	3.39_{3}	------	------	3.32_{6}
Tc	3.69_{3}	3.53_{6}	------	3.70_{7}

The values in table 3 show that at all four stations Pc air has the lowest turbidity and is followed by Npp air;[3] Npc air ranks third, and is followed by Tm and Tc air, although the number of observations within the tropical air is small. This result is in agreement with our knowledge concerning the source regions and vertical structure of the air masses. Pc air, originating over comparatively clean and dry regions and moving swiftly to lower latitudes should be expected to have the lowest turbidity factors. However, as the Pc mass begins to stagnate in the form of an anticyclonic circulation centered over the Middle Eastern States, as is often the case, and is transformed into Npc, the increasingly marked inversions which are thought to be due to subsidence (**8**, p. 19 ff.) keep the acquired pollution concentrated in the surface layers. In this case the turbidity increases until it is higher than that of Npp, wherein the usually steeper lapse rate allows the acquired pollution to be carried upward and thence removed by the winds aloft.[4] The high turbidity of the Tm air is probably due to the large amount of water vapor in its lower layers, and that of the Tc air to its large dust content.

The increase in turbidity as the air masses move across the country is shown for the three common types of air. The increase is most pronounced for Pc air, ranging from 1.87 at Lincoln to 2.54 at Washington, although it is possible that the Washington value is increased by the inclusion of cases of Pc air which might just as well have been called Npc, since in many cases the time of transition from Pc to Npc is quite arbitrary. Npc and Npp air show a smaller increase in turbidity from Lincoln to the east coast. The difference in turbidity between Pc and Npc air at Lincoln and Madison, two stations not far from the Pc source region, might tempt one to ascribe it to local conditions were it not for the rather surprising constancy of the Npp turbidity at the two stations.

In table 4, the turbidities for the stations have been arranged according to seasons: Winter, including December, January, and February; spring, including March, April, and May; and autumn, the months October and November. The mean values, weighted according to the number of days of observations, are given for the individual years and also for the entire period. The values for Blue Hill for the fall of 1933 (including also September) are included in this table.

TABLE 4.—*Mean atmospheric turbidities by air masses, by seasons, by years*

Air	1931			1932		
	Lincoln	Madison	Washington	Lincoln	Madison	Washington
Pc	1.90_{1}	1.85_{1}	2.64_{5}	1.77_{5}	2.00_{3}	2.45_{2}
Npp	2.28_{14}	2.51_{9}	2.41_{5}	2.18_{10}	2.17_{5}	2.43_{6}
Npc	------	------	------	2.10_{10}	2.09_{8}	2.42_{6}
Tm	------	------	------	------	------	------
Pc	1.77_{1}	1.94_{2}	2.64_{3}	1.89_{5}	2.03_{2}	2.69_{3}
Npp	2.69_{13}	2.85_{8}	2.73_{2}	2.53_{7}	2.65_{4}	2.65_{4}
Npc	2.86_{3}	2.76_{11}	3.02_{1}	2.94_{2}	2.68_{6}	2.95_{11}
Tm	------	------	------	------	------	3.46_{3}
Tc	4.28_{1}	3.60_{5}	3.71_{7}	3.33_{3}	3.16_{1}	------
Pc	------	------	------	1.69_{1}	1.97_{6}	2.49_{3}
Npp	2.29_{17}	2.19_{13}	2.27_{8}	2.14_{8}	2.38_{4}	2.25_{3}
Npc	------	2.40_{1}	3.24_{2}	2.42_{3}	2.34_{2}	2.78_{4}
Tm	------	------	2.96_{2}	------	------	------

Air	1933				Total				Season
	Lincoln	Madison	Washington	Blue Hill	Lincoln	Madison	Washington	Blue Hill	
Pc	1.87_{7}	1.95_{7}	2.20_{4}	1.91_{8}	1.82_{13}	1.95_{11}	2.45_{11}	1.91_{8}	
Npp	2.13_{13}	2.33_{6}	2.70_{6}	2.52_{13}	2.20_{27}	2.37_{20}	2.52_{17}	2.52_{13}	
Npc	2.25_{2}	------	2.57_{6}	2.66_{5}	2.13_{12}	2.09_{8}	2.53_{11}	2.66_{5}	Winter.[1]
Tm	------	------	3.61_{1}	------	------	------	3.61_{1}	------	
Pc	2.26_{5}	2.16_{7}	2.48_{4}	2.21_{10}	2.05_{11}	2.10_{11}	2.59_{10}	2.21_{10}	
Npp	2.53_{8}	3.50_{1}	3.47_{7}	2.73_{2}	2.60_{28}	2.83_{8}	3.10_{13}	2.73_{2}	Spring.
Npc	2.56_{5}	2.78_{7}	2.93_{4}	2.80_{17}	2.73_{10}	2.75_{24}	2.95_{16}	2.80_{17}	
Tm	3.39_{3}	------	------	------	3.39_{3}	------	3.46_{3}	------	
Tc	------	------	------	------	3.57_{4}	3.53_{6}	3.71_{7}	------	
Pc	------	------	------	(2.02_{16})[2]	1.69_{1}	1.97_{6}	2.49_{3}	(2.02_{16})[2]	
Npp	------	------	------	(2.52_{5})	2.24_{25}	2.24_{16}	2.26_{11}	(2.52_{5})	
Npc	------	------	------	(2.61_{8})	2.42_{2}	2.36_{3}	2.93_{6}	(2.61_{8})	Autumn.[3]
Tm	------	------	------	------	------	------	2.96_{2}	------	

[1] December 1930 omitted.
[2] September 1933 included.
[3] September omitted for all years.

The four stations show clearly a seasonal trend in T for all principal types of air. Comparing the winter with autumn values in the last column we see that there exists no clean-cut distinction between the two seasons. The Pc air masses seem to be slightly cleaner in winter than in fall; for Npc air the difference is greater except at Blue Hill whose autumn value is slightly less than the winter value. In the Npp air the turbidity for Madison and Washington is lower in the autumn, while at Blue Hill the turbidity remains the same, and at

[3] This result modifies that found for Washington in a preliminary study made by the author (7) covering the period January 1931 to December 1932. In this study Npp air, on the basis of 31 days' observations was found to be the cleanest, T=2.44, and Pc, on the basis of 18 days' observations, the next cleanest, T=2.64.

[4] This reason is open to doubt, for it might well be that, due to horizontal advection of dust by winds aloft, the net loss of the dust content of an air column is zero. To examine more closely the relative turbidities of Npc and Npp air, the average water contents of both types of air were computed from the Massachusetts Institute of Technology airplane soundings for the year 1933, excluding June, July, August, and September, when no soundings were made. For Npp air, from 12 days' observations, the mean precipitable water content was 11.1 mm; while 25 days of Npc air showed 11.8 mm. Hence, we may assume that the water content of the two types of air is the same. If we also assume that the smoke and dust production within the two air masses is the same, then it follows from the higher turbidities in the Npc air that the concentration of a given amount of dust and water vapor in a thin surface layer causes greater depletion of direct solar radiation than if the dust and vapor had been distributed throughout a thicker layer. This phenomenon may perhaps be explained in the following manner: The reflection of light from a sharp smoke and dust line in the atmosphere (such as occurs very often in the Npc air masses) is greater than the reflection and scattering from the smoke and dust particles in a thicker layer lacking a distinct top (as in Npp air) due to the fact that in the latter case secondary reflection and scattering by the particles is brought into play and so enables more sunlight to pass through the layer.

Lincoln it is slightly larger in the autumn. It is when we compare spring-autumn values that the contrast is striking. For all stations and air masses, each year shows a larger turbidity in the spring than in the autumn. In order to investigate the reason for this difference, I have gathered some aerological data showing the seasonal trend of the water content of the atmosphere for the regions considered.

Since the Linke factor does not distinguish between depletion of solar radiation due, on one hand, to absorption by water vapor and, on the other hand, to scattering by small particles in the atmosphere, we may try to get a measure of the latter effect for winter, spring, and autumn by assuming values of the atmospheric water content for these seasons which are in agreement with some available aerological material. In other words, we may try to obtain measures of atmospheric dust content for winter, spring, and autumn. This is one of the aims of the turbidity coefficient defined by Ångström (**1**, 1930). This turbidity coefficient, β, is claimed to be proportional to the dust content of a column of air and is obtained by measuring the depletion of solar radiation in a spectral band where absorption by water vapor is negligible. However, in order to obtain the Ångström coefficient a recording thermopile and special glass filters are necessary. This apparatus is available in this country only at Washington and Blue Hill. Hence, in order to obtain seasonal comparisons in atmospheric dust content from the observations taken at the two midwestern stations, Lincoln and Madison, values of atmospheric water content must be obtained from another source; namely, the aerological material.

Gregg (**3**) has published data giving the vertical distribution of atmospheric and vapor pressure by months over Mount Weather, Va., and the seasonal means of these elements from aerological observations at Omaha, Nebr., Indianapolis, Ind., Huron, S. Dak., and Avalon, Calif. The observations from Mount Weather were obtained from kite ascensions and are given in monthly means of atmospheric pressure (based on 3 years' observations) and of vapor pressure (based on 1 year's observations); the vapor pressure means, however, are given only to 3 kilometers because of scarcity of observations at higher levels. The western group of observations are seasonal means computed from sounding balloon ascents, the data from which were used up to and including the 7-kilometer level. In addition to the above-mentioned material, I have computed for Dr. H. H. Kimball, in connection with his determinations of atmospheric water content from filter measurements of solar radiation (published in the September 1934 MONTHLY WEATHER REVIEW), a series of comparable atmospheric water contents as determined from the Massachusetts Institute of Technology airplane soundings at the East Boston Airport, which averaged to about 5,000 meters in height. Since these evaluations were made only for the days on which solar observations were possible, they are rather few; but, nevertheless, are therefore more truly representative of the days considered in this paper.

The precipitable water content is defined as the depth of liquid water which would result if all the water in a vertical column through the atmosphere of cross-sectional area 1 square centimeter, were condensed. It is given by the formula

$$N=-6.344\int_{p_0}^{p_1}\frac{e}{p}\mathrm{d}p=-14.60\int_{p_0}^{p_1}e\cdot d\log_{10}p,$$

where N is the depth of precipitable water in millimeters; e is the vapor pressure in mb.; p is the atmospheric pressure; and p_0, p_1 are the pressures at the top and bottom of the air column.

N was found by numerical integration of the data, where vapor pressure means were taken between their respective atmospheric pressure levels, and multiplied into the log of the respective pressure differences and summed up for the air column. The results for the three groups of observations are given in table 5.

TABLE 5.—*Mean precipitable water, by seasons*

	Winter	Spring	Autumn
	Millimeters	*Millimeters*	*Millimeters*
Mount Weather, Va	7.2	13.9	[1] 14.0
Western group	7.9	20.3	24.2
East Boston, Mass	7.4_{13}	9.2_{32}	[1] 13.0_{31}

[1] September omitted.

As expected, the water contents are higher for spring and autumn than for winter. Also the values are considerably higher for autumn than for spring except for Mount Weather. However, the autumn mean for this station is probably too low since it is based on a single year's vapor pressure observations, which includes a dry November, whose water content was 8.1 mm as compared with 19.9 mm in October and 10.6 mm in December for the same station and 10 mm on the basis of 15 days' November observations at East Boston (1933). The Boston values are lower than those of the other groups, probably because they represent only the days when condensation forms did not prevent solar observations.

Hence, we see that although more water vapor seems to be present in the atmosphere in autumn than in the spring, the turbidities are higher in the spring. This must mean that there is more dust and smoke present in the atmosphere over the four stations in the spring than in the autumn. This conclusion is strengthened in the cases of Washington and Blue Hill by the measurements of the Ångström turbidity coefficient, β. For Washington I have computed the seasonal means from two sources—The first from the values published by Ångström (**1**) which covered the period 1903–7 and were determined from measurements by the Astrophysical Observatory of the Smithsonian Institution.

Ångström used the intensities at wave lengths 0.45μ and 0.90μ to determine from two simultaneous equations β, the turbidity coefficient, and α, the size coefficient, which varies from 4 for molecules to 0 for large particles, scattering nonselectively. From these computations, α was found to be 1.24, corresponding to scattering particles of mean diameter slightly larger than 1μ. The second source is the values of β for 1932 presented in the MONTHLY WEATHER REVIEW, determined from measurements made under the assumption that $\alpha=1.3$. For Blue Hill, the β's determined during 1933, under the same assumption regarding constancy of α, were employed. The seasonal means of the β's are presented in table 6.

TABLE 6.—*Ångström turbidity coefficients, means by seasons*

	Winter	Spring	Autumn
Washington, 1903–07	0.063	0.136	0.056
Washington, 1932	[1] $.079_{11}$	$.099_{29}$	[2] $.066_{12}$
Blue Hill, 1933	$.062_{14}$	$.064_{32}$	$.055_{30}$

[1] January omitted as observation began in February.
[2] September omitted.

The above values show that the β's are higher in spring than in autumn for the three sets of observations; this agrees with the conclusions derived from the Linke factor data for Washington and Blue Hill, showing greater dust content in the spring than in the autumn. Therefore, it is justifiable to make similar conclusions regarding a spring-autumn contrast in dust and smoke for Lincoln and Madison, where equipment for measuring the β's is not available.

A surprising feature of table 6 is the presence of larger β's for the three sets of observations in the winter than in the autumn. The winter-autumn Linke factors in table 4 for Washington and Blue Hill showed no such distinct contrast. However, assuming the Linke factors to be slightly lower in winter than in autumn, and noting from table 5 that the atmospheric water contents for the two stations in the autumn are twice those in the winter, we are led to the conclusion that there exists more dust and smoke (smoke probably predominating) in the atmosphere over Washington and Blue Hill in the winter than in the autumn. This conclusion is derived only from considerations of the Linke factors in conjunction with the aerological data. The Ångström coefficients presented in table 6, however, which are derived from an entirely separate set of observations, are in agreement with the above conclusion, and, therefore, we feel justified in saying that over Lincoln and Madison more dust and smoke seems to be present in the winter than in the autumn.

Thus far we have concluded that there is present more dust and smoke in spring and also in winter than in the autumn.[1] For Blue Hill and Washington, we arrived at these conclusions from two sets of data: first, the Linke factors in conjunction with aerological data; and, second, the Ångström coefficients. Inasmuch as we found that the conclusions derived from the first set of data were supported by the second set of data, we felt justified in extending these conclusions to Lincoln and Madison, where means for measuring the Ångström coefficients are lacking. In contrast to the Ångström coefficients the conclusions derived from the first set of data were qualitative; if quantitative results were desired, then definite assumptions as to mean water contents for the various seasons would have to be made. This procedure would be safe only at Blue Hill, where water contents were determined for about two-thirds of the days on which the Linke factors were observed. Now, in seeking a winter-spring contrast in dust and smoke content, it is impossible to derive conclusions qualitatively, since both the Linke factors and water contents are higher in spring than in winter, as shown in tables 6 and 4. In this case, then, quantitative methods must be applied. From table 6, the water contents over East Boston for winter and spring are 7.4 mm and 9.2 mm, respectively. From the values given in table 2, we find that an atmosphere containing 5 mm of precipitable water has for its Linke factor 1.65, approximately, and for an atmosphere containing 10 mm precipitable water, T=2, approximately. From linear interpolation, we find that w=7.4 mm corresponds to T=1.81, and w=9.2 mm corresponds to T=1.94. The mean of the observed T's for winter and spring weighted according to the number of days of observations, were found from table 4 and results of the computation are given in table 7.

[1] This is in accord with the determination of the dust content of the surface air at Washington in 1922-25, MO. WEA. REV., vol. 53, p. 243, table 1.

TABLE 7.—*Winter vs. spring dust turbidities at Blue Hill, 1933*

	w	T_w	$T_{obs.}$	$T_d=T_{obs.}-T_w$
	mm			
Winter	7.2	1.81	2.36_{26}	0.55
Spring	9.4	1.94	2.59_{29}	.65

Hence, for Blue Hill, 1933, more dust and smoke was present in the spring than in the winter in the ratio, 0.65/0.55=1.18. Also, from the β's given in table 6, more dust and smoke is indicated for the spring in the ratio 0.064/0.062=1.03. The discrepancy between the two ratios may be due to the fact that the β's were found from 46 days' observations, whereas the T's were found from 55 days' observations.

CHANGES OF TURBIDITY WITHIN AN AIR MASS

Three situations wherein observations were taken within the same air mass are presented below:

1. *Situation of January 22–24, 1933.*—Npp advanced east and northeastward behind a LOW which followed a path from Lake Michigan, on the 22d, to the mouth of the St. Lawrence River, on the 23d. The air mass reached Lincoln on the 22d, Madison on the 23d, Blue Hill on the 24th, and finally, Washington on the 24th. Blue Hill during most of the 23d was in a frontal zone between Npp and Tm. The turbidities are presented in table 8; the subscripts attached to the T's refer to the number of individual observations made on the day in question.

TABLE 8.—*Turbidities in an advancing Npp air mass, Jan. 22–24, 1933*

Lincoln	Madison	Blue Hill	Washington
Jan. 22, $T=1.88_3$	Jan. 23, $T=1.92_3$	Jan. 23, $T=2.50_5$ Jan. 24, $T=2.03_7$	Jan. 24, $T=2.59_3$

The increase in T from 1.88 at Lincoln to 2.59 at Washington is undoubtedly due to the different trajectories of the air columns present over each station. For Lincoln, Madison, and Blue Hill the trajectories were over relatively clean regions, since the winds at the time of observation were mostly from the west and northwest. For Washington the trajectory lay over the industrial part of the country; hence, considerable pollution principally in the form of smoke was acquired. At Blue Hill, the effect of Tm aloft is shown on the 23d, when T=2.50; on the next day, however, when Blue Hill was well within the Npp current, T dropped to 2.03.

2. *Situation of December 14–16, 1931.*—On the 14th, a Npc air mass covered the United States from the Rockies to the Mississippi River and spread eastwards to Washington before 8 p. m. the same day. On the 15th the mass split into two anticyclonic centers, one over the East and the other over the Rockies, so that Lincoln on the 16th was in a region of convergence between the two HIGHS and had at the surface a thin layer of fresh Npc air coming from the northwest, and at upper levels the older Npc air coming from the south. The values of T are given in table 9.

TABLE 9.—*Turbidities in an advancing Npc air mass, Dec. 14–16, 1931*

Lincoln	Madison	Washington
Dec. 14, T=1.96$_5$	Dec. 14, T=1.94$_3$	Dec. 15, T=2.42$_6$
Dec. 15, T=2.13$_6$		
Dec. 16, T=2.22$_5$		

The increase in T from 1.96 in the Midwest to 2.42 in Washington on the following day shows the rapid pollution of the Npc air as it travels eastward. Because of the subsidence inversion which is thought to exist in the Npc air, this acquired pollution is probably concentrated in a thin surface layer. At Lincoln the successive increases in T on the 14th, 15th, and 16th show how the turbidity is increased when the direct flow of Npc from the northwest is replaced by a flow from southerly quarters due to movement of the high pressure center eastward.

3. *Situation of October 16–21, 1931.*—A large body of Npp air covered a major portion of the continent on the 15th; on the night of the 15th–16th it invaded Madison, and on the morning of the 17th, Washington. The air mass stagnated, the anticyclonic center remaining over West Virginia from the 17th to the 21st. On the night of the 21st–22d, fresher Npp reached Washington. The values of T are given in table 10.

TABLE 10.—*Turbidities in an advancing Npp air mass, Oct. 16–21, 1931*

Lincoln	Madison	Washington
Oct. 15, T=2.03$_3$	Oct. 16, T=2.27$_4$	Oct. 17, T=2.14$_4$
16, 1.98$_1$	17, 1.87$_3$	19, 2.43$_8$
17, 2.13$_6$	19, 1.84$_1$	20, 2.24$_8$
18, 2.45$_4$	20, 3.49$_4$	22, 2.12$_8$
19, 2.33$_4$		

The Lincoln T's show a gradual increase from about 2 on the 15th-16th, to about 2.4 on the 18th-19th, corresponding to the shifting of the wind on the 17th from the northwest, which brought in fresh Npp, to the south, bringing in older Npp. The high turbidity at Madison on the 16th may be explained by local conditions since the morning observer reports smoke and a visibility of 8 miles with a northwest wind. The wind shifted into the south on the 19th and the older return air on the 20th shows a much larger value, T=3.49; here, again, the observer reports smoke and a visibility of 8 miles with a south wind. The turbidity at Washington increases from 2.14 on the 17th, when the fresh Npp current came in, to 2.43 an the 19th, after the high had stagnated. The drop in T to 2.24 on the 20th, when conditions were practically unchanged cannot be explained from the available data. However, the decrease to 2.12 on the 22d is probably due to fresh Npp displacing the older Npp.

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BIBLIOGRAPHY

(1) Ångström, A., Atmospheric transmission of sun radiation and dust in the air. Geografiska Annaler, 1929, Bd. 11.
——— Atmospheric transmission of sun radiation, Pt. II, Ibid, 1930, Bd. 12.

(2) Feussner, K., and Dubois, P., Trübungsfaktor, precipitable water, Staub. Gerl. Beitr. z. Geophysik, 1930, Bd. 27.

(3) Gregg, W. R., Mean values of free-air barometric and vapor pressures, temperatures, and densities over the United States. Mo. WEA. REV., 1918, v. 46, pp. 11–20.

(4) Haurwitz, B., Daytime radiation at Blue Hill Observatory in 1933 with application to turbidity in American air masses. Harvard Meteorological Studies, no. 1, 1934.

(5) Kimball, H. H., Solar radiation measurements. Mo. WEA. REV., 1932, v. 60, pp. 26–27.

(6) Linke, F., Transmissionskoeffizient und Trübungsfaktor. Beitr. z. Phys. d. fr. Atmos., 1922, Bd. 10.

(7) Wexler, H., A comparison of the Linke and Ångström measures of atmospheric turbidity and their application to North American air masses. Trans. Amer. Geophys. Union, 14th Annual Meeting, April, 1933, Washington, pp. 91–99.

(8) Willett, H. C., American Air Mass Properties. Papers in Physical Oceanography and Meteorology, Mass. Inst. of Techn. and Woods Hole Ocean. Inst., 1933.

SOME WIND VELOCITY CORRELATIONS

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Two studies of wind velocity in as many relationships, employing the methods of correlation analysis, are reported in this paper:

1. *True versus indicated velocity.*—Among the assets of the meteorologist that a banker would classify as "slow" rather than frozen, are the data of wind velocity that were written down in the records before the reduction to true velocity commenced January 1, 1932. The precise relation between true velocity and indicated has been set forth in the papers by Marvin entitled "A Rational Theory of the Cup Anemometer" (MONTHLY WEATHER REVIEW, **60,** 1932, pp. 43–57) and "Recent Advances in Anemometry" (MONTHLY WEATHER REVIEW, **62,** 1934, pp. 115–120), where the lines that represent the functional relation show a pronounced curvature near the origin. In the present study, the observed results flow from the official conversion table in Instructions No. 14, 1931.

It is obvious that the conversion table just mentioned cannot be applied to monthly averages, inasmuch as the latter comprise a wide spectrum of different velocities, each requiring a different correction. The object of this study is to discover the law of relationship of the monthly means of the indicated velocities to the means of the true velocities.

In preparing this paper the hourly wind movement for each of the 236,320 hours in the 27 years, 1905–31, was converted to true velocity by applying the official correction. The results were averaged and compared with the averages of the raw data. The help of eight students in the University of Wisconsin who made the conversions and averages, and of Messrs. Batz and Lorenz of the staff of the Madison Weather Bureau Office in checking the arithmetic, is gratefully acknowledged.

In the case of the three-cup anemometer, the official conversion table adds 1 mile to all indicated velocities from 0 to 16, no correction to 26, and subtracts about 12.5 percent from higher indicated velocities. The averages show a difference of precisely 1 mile at all velocities below 9 miles per hour, indicated (10 miles per hour true). Above those limits the few available cases